ue exceeds a threshold, with the accompanying audible signal of a certain frequency and duration.

The inclusion of MIPEX IR sensors, MSP430G2553 microcontroller and LCD in a portable meter of methane concentrations will provide a packaged unit with the independent power supply, capable to operate for a long period of time without replacement or recharging of the feed element.

The equipment can be added with wireless transfer of data on methane concentration to an operator's board.

The system of real-time data collection and control needs no high rate of exchange as a rule. For this reason, the wireless data communication between the methane concentration meter and the operator's board can use IEEE802.15.4 (ZigBee) supporting standard [17].

This standard sets the maximum data rate of 250 Kbps and the communication range of the order of a few tens meters within line of sight. A feature of the nets based on IEEE802.15.4 standard is the capacity to implement any topology, including cellular [18].

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OPTIMIZATION OF EXPENDITURES FOR LABOR PROTECTION AT DEEP MINING

The analysis of the state of the labor protection and industrial safety system of Russia's coal mining industry demonstrates that the rise in the investment into the measures directed at improving does not lead to a sufficient fall in the risk of occupational injuries and occupational diseases. Moreover, it has been found that at a number of the industry's enterprises the risk of occupational traumatism and occupational diseases follows either an upward trend or a wavelike trend with minimum and maximum values. One of the ways of achieving an increase in the effectiveness of the HSE system is determining the amount of expenditures that leads to the minimum values of the risk of occupational injuries and occupational diseases, which can be considered 'economically justifiable risks'. In the article the procedure of calculating investment into industrial security and labor protection for coal mining companies is proposed. The method for calculating optimal expenses on preventing occupational injuries and economically justifiable risk is elaborated.

Key words: *coal mine, labor protection, accident rate, coal mining industry, industrial security, cost optimization, economically viable risk*
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Introduction

The possibility of ensuring the admissible values of the risk of occupational diseases, injuries and accidents is determined by the expenses on industrial safety and labor protection [1, 2]. The correlation between these expenses for OOO Prokopyevskugol Corporation for 2010–2013 is presented in **Fig. 1**.

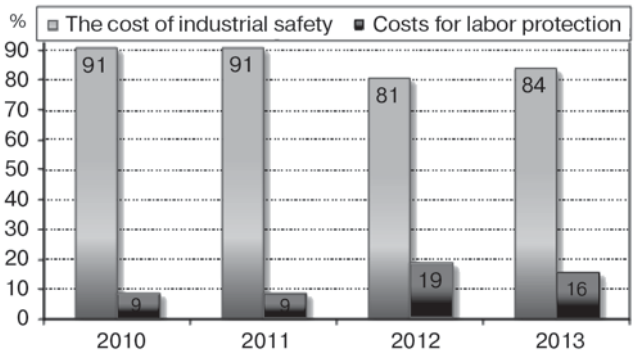

Fig. 1. The correlation between the expenditures on industrial safety and labor protection

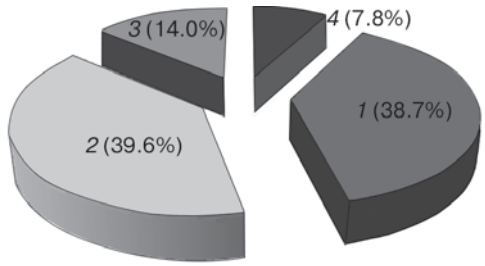

Fig. 2. The distribution of expenses on labor protection at OOO Prokopyevskugol Corporation:
***1* – the funds allocated for organisational measures for the protection of labor; *2* – funds allocated to the prevention of occupational diseases; *3* – the funds allocated for PPE; *4* – other**

The expenditures on industrial safety are significantly higher than the ones on labor protection [3, 4, 5]. At that, the expenditures on industrial safety include the pre-appraisal training and appraisal for technicians and engineers in the field of industrial safety; the licensing of certain activities; the state examination of project documentation; the examination of project documentation on industrial safety; the elaboration of the project design documentation (including measures, conclusions etc.) by external companies; the diagnostics and assessment examination of technical equipment, buildings and constructions; equipment and resources for endogenous fire prevention, coal seam degasification, fire safety and dust-explosion protection; equipping and maintaining the mine rescue brigade; control facilities and alarm system.

Table 1. Value of coefficients *a*. *b* in the formula (1) and magnitude of correlation index k_c

Coal mining enterprise	*a*	*b*	k_c
Koksovaya mine	7.56	–0.088	0.9
Zenkovskaya mine	2.5594	–0.909	0.89
Voroshilov mine	4.955	–0.542	0.8
Dzerzhinsky mine	6.0567	–0.519	0.92
Tyrganskaya mine	4.4158	–0.513	0.88
Krasnogorskaya mine	3.9412	–0.47	0.85
Ziminka mine	2.566	–0.641	0.85
OOO Prokopyevskugol Corporation	118.12	–0.984	0.77

Labor safety measures include personnel's training and the safety knowledge assessment; the assessment of workplaces with respect to working conditions; measures to mitigate occupational hazards; the industrial sanitary inspection; the elaboration of documentation (including measures, conclusions etc.) by external companies; protective gear; the first aid facilities maintenance; medical screening; expenses on washing and mending protective clothes etc. [6–8].

An integral part of measures of labor protection is such measures that directly result in the prevention or decrease of occupational traumatism. The set of measures should be determined in relation to the main causes of occupational injuries [9–12].

The conducted analysis showed that at OOO Prokopyevskugol Corporation, among all causes of occupational injuries, on average more than 75% amounts to organizational causes that include inadequate operating procedures, safety violations during vehicle operation, inadequate works engineering, lack of training in how to use safe work practices, violation of work discipline, allowing an employee to work in the field in which they have not been trained etc. It has to be noted that for every specified mine the percentage of organizational causes is different. The minimum value characterizes Koksovaya mine (63.6%) and the maximum is seen at Zenkovskaya mine (87.7%). The other causes are the following: the structural defects, flaws and insufficient reliability of machines, mechanisms and equipment; the operation of defective machines, mechanisms and equipment; flawed technological process; the inadequate maintenance and flawed organization of workplaces; poor technical state of the facilities, constructions and territories; and non-use of protective gear. On average, they account for 0.4%, 1.2%, 2.1%, 14.6%, 2.9% and 0.4% respectively.

Expenses directed at lowering the influence of organizational factors that induce occupational injuries include personnel's training and the safety knowledge assessment; the assessment of workplaces with respect to working conditions; measures to mitigate occupational hazards; the elaboration of documentation (including measures, conclusions etc.) by external companies [13–16]. In the overall labor protection cost structure of the corporation, for 2010–2013, such expenses account for 7.8% on average and change in the specified period from 15.3% in 2011 to 3.3% at the end of 2013 (**Fig. 2**).

Methodology

In accordance with the method the economic damage of the occupational injuries in the mines of OOO Prokopyevskugol Corporation was calculated. Furthermore, it was demonstrated that the dependence of occupational injuries damage *Y* from expenses on organizational measures of labor protection *Z* is determined as a power law with the correlation ratio k_c exceeding 0.75 (**Table 1**):

$$Y = aZ^b. \quad (1)$$

In all the specified cases, the damage from occupational traumatism decreases with the growth of expenses, which suggests that investing into measures directed at improving labor protection has a positive effect.

As it was stated earlier, the main components of the economic damage caused by occupational traumatism that

were reviewed are as follows: loss of profit resulting from a decrease in coal production, compensation for loss of life or occupational injuries as well as the cost of treatment and rehabilitation provided to the victims of occupational accidents [17–20]. An approximate correlation between these components of the economic damage determined by the circumstances of OOO Prokopyevskugol Corporation is presented in **Fig. 3**.

Having analyzed the data shown in this figure, we can see that death grants paid to families or compensation for occupational injuries paid to the victims of occupational accidents represents the largest share in the economic damage structure, which reaches up to 75% at the fixed coal price values for 2012. Moreover, the damage induced by a decrease in coal production or the cost of victims' rehabilitation account for 24.5% and 0.7% respectively.

The performed calculations also demonstrated that the amount of damage depends on the actual price for a ton of coal and the lump sum death grants or compensation for occupational traumatism. With the increase of the price for a ton of coal from 1200 RUB to 3000 RUB, depending on the different types of compensation payments that are determined by the 'cost of human life' that equals 1 million RUB, 5 million RUB and 10 million RUB, the economic damage rises by 17%, 6% and 4% respectively. At the same time, a change in compensation payments affects the amount of damage to a far greater extent. Thus, at a coal price of 2000 RUB, the increase in the compensation payment from 1 million RUB to 10 million RUB leads to almost a six-fold increase in the economic damage. This way an increase of compensation amount through legislation will lead to a rise in employers' commitment to lowering occupational traumatism rate at coal mines.

A comparative analysis of development systems used at OOO Prokopyevskugol Corporation coal mines was carried out for the degree of risk of occupational diseases and traumatism and the correspondent economic damage.

The following mining types, which are widely implemented at OOO Prokopyevskugol Corporation, were selected for the analysis: shield mining with downfall; shield support; sublevel entry mining with hydraulic winning; long wall mining and sublevel entry mining.

The analysis of occupational hazards for each of the mentioned mining types demonstrated that the highest number of such factors characterize the shield types of mining (a break of rock under the shield, shield suspension, timber damage in coal chutes, roof caving resulting from unstable positioning of coal blocks, methane gassing of the under shield space due to poor ventilation, the blocking of air passages and ventilation failures that lead to a concentration of methane exceeding the admissible limit value);the lowest number of such factors is seen in long wall mining and sublevel entry mining(unstable position of miners during face support, collapse and burst of coal blocks and rock in the walls, use of explosives including the ones for breaking boulders, sudden roof subsidence causing the deformation of timbering and the run of explosive and harmful gases) and minimal for the sublevel entry mining with hydraulic winning (high concentration of methane in stope domes when they are filled with collapsed rock, poor ventilation as a result of mine ventilation pressure drop).

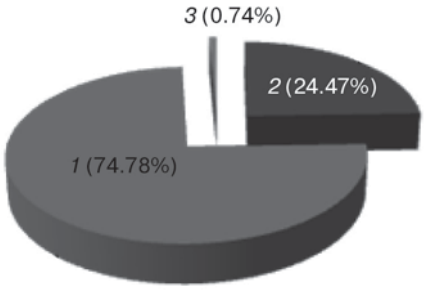

Fig. 3. The correlation between the components of the economic damage:
***1* – compensation; *2* – the damage from the downtime;**
***3* – costs for the rehabilitation of victims**

This analysis is also confirmed by the calculations of the average traumatism rate for the specified period: its value is 0.03, 0.039 and 0.021 for long wall mining and sublevel entry mining, shield mining with downfall and sublevel entry mining with hydraulic winning respectively.

As for the risk of occupational diseases that different occupational hazards pose, here the situation is slightly different [21–24]. In comparison with other mining types, sublevel entry mining with hydraulic winning accounts for the smallest number of diseases associated with cochlear neuritis, vibration white finger and damage of respiratory system. At the same time, diseases caused by other factors (chronic cold-related diseases etc.) are 8 times more frequent for shield mining and 2.5 times for long wall mining and sublevel entry mining (**Fig. 4**).

Thus, for every specified type of mining, different occupational hazards that cause various diseases have the prevailing influence on occupational diseases. However, they determine roughly equal overall risks of occupational diseases for all the types – these risks amount to 0.014, 0.011 and

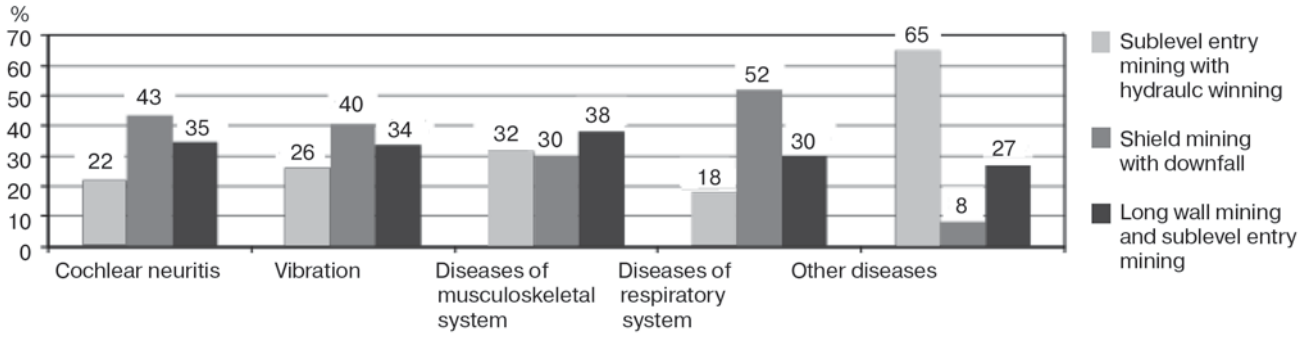

Fig. 4. The correlation between the number of occupational diseases and different types of mining

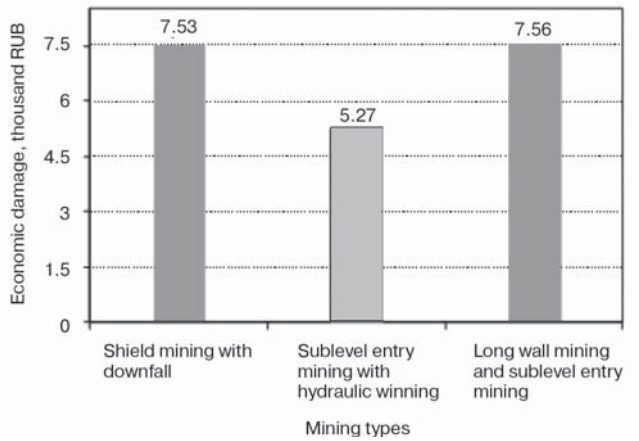

Fig. 5. The economic damage related to the peculiarities of the technological process with different types of mining

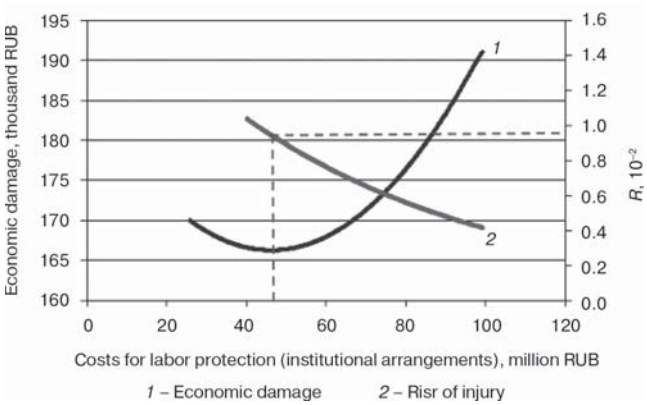

Fig. 6. Determining optimal expenses on traumatism prevention and economically justifiable risk at AO SUEK-Kuzbass

0.016 for shield mining, long wall mining and sublevel entry mining and sublevel entry mining with hydraulic winning.

Traumatism and occupational diseases caused by the influence of occupational hazards lead to economic damage. To calculate it, a method elaborated by D. Gospodarikov was used. The results of the economic damage calculation carried out for the average traumatism and occupational diseases rate can be found in **Fig. 5**. As we can see, the economic damage associated with traumatism and occupational diseases for sublevel entry mining with hydraulic winning is about 30% lower than the damage for other types of mining.

The economic damage from traumatism decreases with an increase in expenses on labor protection. This happens mainly as a result of the fall in the risk of occupational traumatism of all types and, consequently, the decrease of compensation payments as well as the decrease in the loss of production that are proportional to the period of time when the production is shutdown due to equipment maintenance, rehabilitation or miners job rotation. The damage increases with the rise of price on coal and the growth of lump sum death grants or compensations for occupational injuries.

On the other hand, the expenses on labor protection related to measures directed at the prevention of traumatism always grow in absolute magnitude.

In relation to this, there is an issue of calculating economically justifiable (optimal) expenses (Z_{op}) on lowering the rate of occupational injuries and the risk correspondent to such expenses, i.e. economically justifiable risk.

In order to determine the amount of optimal expenses on lowering the traumatism rate, we suggest using the minimum value of the objective function that is a sum of economic damage (ΔP) that includes the loss of profit caused by a decrease in production, miners rehabilitation costs, death grants and compensation for injuries.

This objective function can be presented in the following way:

$$\Delta P = C \cdot \Delta D(Z_{lp}) + y(Z_{lp}) + Z_{lp}, \quad (2)$$

where C is price for a ton of coal, RUB per ton; $\Delta D(Z_{lp})$ is the loss of coal production as a result of traumatism, ton; $y(Z_{lp})$ is the economic damage resulting from traumatism, million RUB; Z_{lp} is financial investment into the system of labor protection directed at lowering the traumatism rate, million RUB.

Research results

For minimizing the objective function, we used the results of the calculations for the economic damage from traumatism and the data on expenses that correspond to every calculated value of economic damage. The calculations were performed for every mine and for all mines of OOO Prokopyevskugol Corporation and AO SUEK-Kuzbass.

The procedure for determining optimal expenses on labor protection and economically justifiable risk for the circumstances of AO SUEK-Kuzbass is shown in **Fig. 6**.

Similar calculations were carried out for every mine and for all mines at OOO Prokopyevskugol Corporation.

The analysis of the calculations shows that for OOO Prokopyevskugol Corporation the value of optimal expenses on the organizational measures directed at lowering the rate of traumatism add up to 0.47 million RUB – 2.35 million RUB. The overall value for the enterprise reaches 5.95 million RUB (**Table 2**). At the same time, this value is estimated to be 46.4 million RUB for AO SUEK-Kuzbass corporation.

Table 2. The values of optimal expenses and economically justifiable risk

Coal mining facilities	The volume of optimal expenses, million RUB	Economically justifiable risk of occupational injuries
OOO Prokopyevskugol Corporation	5.95	0.012
Koksovaya mine	0.47	0.015
Zenkovskaya mine	1.6	0.004
Voroshilova mine	1.82	0.012
Dzerzhinsky mine	2.28	0.006
Tyrganskaya mine	1.46	0.005
Krasnogorskaya mine	2.35	0.015
Ziminka mine	1.39	0.008
AO SUEK-Kuzbass	46.4	0.009

Every expenses value corresponds to its risk value, which is considered the so termed economically justifiable risk. This risk is determined by the current level of the labor protection system at every mine and each corporation and can be used as a certain planned parameter for assessing the current risk of occupational injuries. Comparing the values of economically justifiable risk with the current traumatism risk, in the framework of a certain corporation, allows for singling out such mines that should be allocated additional funding.

For instance, economically justifiable risk for OOO Prokopyevskugol Corporation amounts to 0.012 while it is 0.009 for AO SUEK-Kuzbass. At the same time, the given risk for Koksovaya mine and Krasnogorskaya mine is estimated to be 0.015, which means it is a priority that these enterprises receive investment for measures of labor protection related to traumatism. The similar comparison of economically justifiable risks for OOO Prokopyevskugol Corporation and AO SUEK-Kuzbass highlights the need to increase the expenses on traumatism prevention for OOO Prokopyevskugol Corporation, as the economically justifiable risk for this enterprise is 25% higher than this risk for AO SUEK-Kuzbass.

Conclusions

As shown by calculations of the economic damage from injuries, its value decreases with increasing costs. This happens mainly due to the reduction of risk of occupational injuries of all types and therefore reduce compensation payments, as well as reducing loss of the mineral, which is proportional to the time during which stopped its production due to downtime associated with equipment repair, rehabilitation and rotation of miners. As follows from calculations, the damage increases with the increase in coal prices and an increase in lump-sum compensation payments for the loss of life and injury. The analysis of the effectiveness of the investment into the system of labor protection on the basis of economically justifiable risk allows for identifying such coal mining enterprises that need prioritized financing of measures to lower the traumatism rate.

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